UPPSC-AE 2025

Uttar Pradesh
Public Service Commission

Combined State Engineering Services Examination

Assistant Engineer

Electrical Engineering

Networks and Systems

Well Illustrated **Theory** *with*
Solved Examples and **Practice Questions**

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Networks and Systems

Contents

CHAPTER 1 Basic Concepts

1.1 Introduction

Electric circuit theory is the most fundamental branch of electrical engineering. Other branches such as power systems, electric machines, communications, control system and instrumentation are based on electric circuit theory. Thus it is very essential to go through the basic concepts of circuit theory to understand the electrical engineering.

We commence our study by knowing some basic concepts include charge, current, voltage, circuit elements, power and energy.

1.2 Basic Terminology

1.2.1 Charge

- Charge is an electrical property of the atomic particles of which matter consists, measured in Coulombs (C).
- According to experimental observations, the only charges that occur in nature are integral multiple of the electronic charge ($e = -1.602 \times 10^{-19}$ C).
- The Coulomb is a large unit for charges. In 1C of charge, therefore

$$\frac{1}{(1.602 \times 10^{-19})} = 6.24 \times 10^{18} \text{ electrons}$$

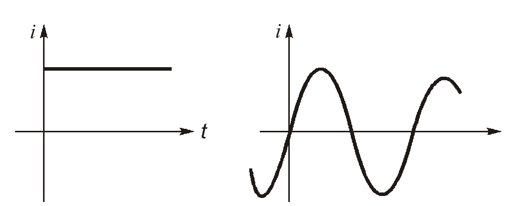
- The law of conservation of charge states that a charge can neither be created nor be destroyed, can be only transferred.

1.2.2 Current

- The phenomenon of transferring charge from one point in a circuit to another is described by the term electric current. An electric current may be defined as the time rate of net motion of electric charge across a cross-sectional boundary. A random motion of electrons in a metal does not constitute a current unless there is a net transfer of charge with time. In equation form, the current is,

$$\boxed{i = \frac{dq}{dt}}$$

- If the charge q is given in coulombs and the time 't' is measured in seconds, then current is measured in Amperes.
- A current that is constant in time is termed as direct current, or simply dc, and is shown in Fig. (a).
- A current that vary sinusoidally with time is often referred as alternating current as shown in Fig. (b).



(a) (b)

Example - 1.1 The charge in a capacitor is given by

$$q = \left(v + \frac{1}{3}v^3\right)$$

If the voltage across this capacitor be $v(t) = \sin t$, the current $i(t)$ through the capacitor is

(a) $(1 + \sin^2 t)\cos t$
(b) $(1 + \sin^2 t)$
(c) $(1 + \cos^2 t)\sin t$
(d) $\sin^2 t \cos t$

Solution : (a)

The current through the capacitor is, $i = \frac{dq}{dt} = \frac{dq}{dv}\cdot\frac{dv}{dt}$

Now, $\frac{dq}{dv} = (1 + v^2)$ and $\frac{dv}{dt} = \cos t$

$\therefore$ $i = (1 + v^2)\cdot\cos t$

$= (1 + \sin^2 t)\cdot\cos t$

1.2.3 Voltage

- To move the electrons from one point to other point in particular direction external force is required. In analytical circuit external force is provided by emf and it is given by,

$$v = \frac{dw}{dq}$$

where a differential amount of charge dq is given with a differential increase in energy dw. The quantity "energy per unit charge" or identically, "work per unit charge", is given the name voltage. Thus, the voltage across a terminal pair is a measure of the work required to move the charge through the element.

- A voltage can exist between a pair of electrical terminals whether a current is flowing or not. An automobile battery, for example, has a voltage of 12 V across its terminals even if nothing whatsoever is connected to the terminals.

1.2.4 Power

- If potential is multiplied by the current, dq/dt, as

$$\frac{dw}{dq}\times\frac{dq}{dt} = \frac{dw}{dt} = p$$

the result is seen as to be a time rate of change of energy, which is power 'p'. Thus power is the product of potential and current,

$$p = vi = \frac{v^2}{R} = i^2R, \quad \text{where } R \rightarrow \text{resistance}$$

- It is measured in Watt (W).

1.2.5 Energy

- The capacity to do the work is called as energy. Energy as a function of power is found by integrating equation (A). Thus total energy at time 't' is the integral

$$w = \int_{-\infty}^{t} p\,dt$$

- The change in energy from time t_1 to time t_2 may similarly be found by integrating from t_1 to t_2.
- It is measured in Joules or Watt-hours (Wh)

$$1 \text{ Wh} = 3600 \text{ J}$$

1.2.6 Electric Circuits and Network

- An electric circuit is an interconnection of electrical elements.
- Network is any possible inter-connection of circuit elements or branches. Circuit is a closed energized network.

1.3 Circuit Elements

- Any individual circuit component (inductor, resistor, capacitor, generator etc.) with two terminals, by which it can be connected to other electrical components.
- If the voltage across the element is linearly proportional to the current through it, then element is called as a **resistor**.
- If the terminal voltage is proportional to *derivative of current* with respect to time, then element is called as a **inductor**.
- If the terminal voltage is proportional to *integral of current* with respect to time, then element is called as a **capacitor**.
- If the terminal voltage is completely independent of current, or the current is completely independent of voltage, then element is called as an **independent source**.
- The element for which either the voltage or current depend upon a current or voltage elsewhere in the circuit; such elements are called as **dependent source**.

1.4 Classification of Circuit Elements

1.4.1 Active and Passive Elements

- If we have a network element that is absorbing power i.e. energy delivered to the element $\left(\int_{-\infty}^{t} v(t)i(t)dt\right)$ is positive, then the element is *passive element*. Eg: resistor, inductor, diode and capacitor.
- If we have a network element that is delivering power i.e. energy delivered to the element $\left(\int_{-\infty}^{t} v(t)i(t)\,dt\right)$ is negative, then the element is *active element*. Eg: Independent sources, transistor and op-amp.

NOTE: An active element can provide power or power gain to the circuit for infinite duration of time, that is why charged capacitor or inductor are not active elements.

1.4.2 Bilateral and Unilateral Elements

- For a *bilateral element*, the voltage current relationship is the same for current flowing in either direction. Eg: resistor, inductor and capacitor.
- For a *unilateral element*, the voltage current relationship is different for two directions of current flow. Eg: diode.

1.4.3 Lumped and Distributed Elements

- *Lumped elements* are considered as the separate elements which are very small in size. For Eg: resistor, inductor and capacitor.
- *Distributed elements* are not electrically separable. These are distributed over the entire length of the circuit. Eg: Transmission lines.

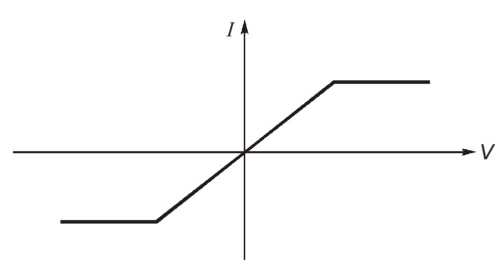
1.4.4 Linear and Non-Linear Elements

- An element that follows *additivity* and *homogeneity property* for relationship between excitation and response is called a *linear element*.
- An element that does not follow *additivity* and *homogeneity property* for relationship between excitation and response is called a *non-linear element*.

NOTE

- The *homogeneity property* requires that if excitation is multiplied by a constant, then the response gets multiplied by the same constant.
- The *additivity property* requires that the response to a sum of inputs is the sum of the responses to each input applied separately.

Example - 1.2 The following v-i characteristic of an element is shown below. The element is



(a) Non-linear, unidirectional, passive
(b) Linear, bidirectional, active
(c) Non-linear, bidirectional, passive
(d) Non-linear, unidirectional, active

Solution : (c)

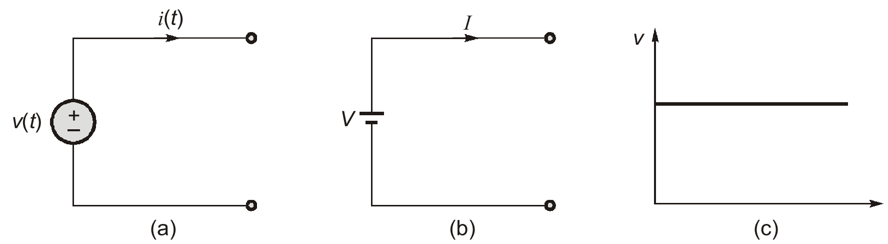
- As characteristics is similar in opposite quadrants, then the element is bidirectional.
- Element is passive as ratio of V/I is not negative at any point on characteristics curve.

1.5 Sources

- Sources are classified as voltage sources and current sources, and further as independent and dependent sources.

1.5.1 Independent Voltage Source

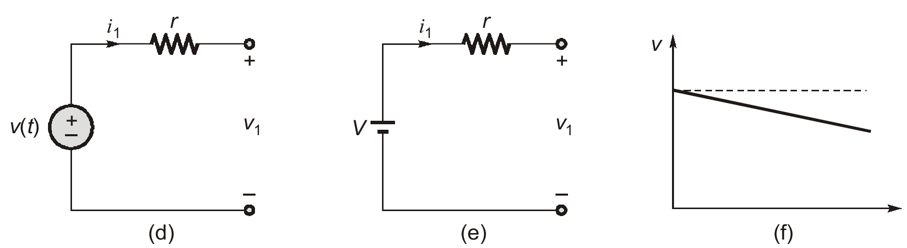
- An ideal voltage source is two-terminal element which maintains a terminal voltage v(t) regardless of the value of the current through its terminals; as shown in figure (a) and (b). Internal resistance of an ideal voltage source is equal to zero.



(Ideal voltage source and v-i characteristics)

- In a practical voltage source, the voltage across the terminals of the source keeps falling as the current through it increases, as shown in figure. This behaviour can be explained by putting a resistance in series with an ideal voltage source, as in figure (d). Then we have the terminal voltage v_1 as

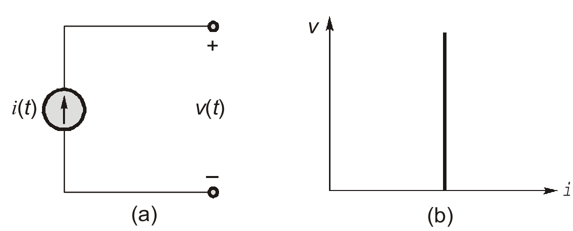
$$\boxed{v_1 = v - i_1 r}$$



(Practical voltage source and v-i characteristics)

1.5.2 Independent Current Source

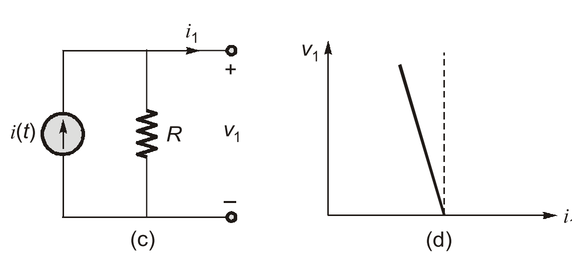
- An ideal current source is a two-terminal element which maintains a current $i(t)$ flowing through its terminals regardless of the value of the terminal voltage as shown in figure (a). The internal resistance of ideal current source is infinite.



(Ideal current source and v-i characteristics)

- In a practical current source, the current through the source decreases as the voltage across it increases, as shown in figure (d). This behaviour can be explained by putting a resistance across the terminals of the source, as in figure (c). Then the terminal current is given by,

$$\boxed{i_1 = i - \frac{v_1}{R}}$$



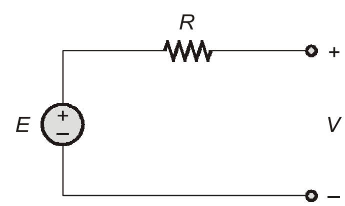
(Practical current source and v-i characteristics)

Example - 1.3 The internal voltage drop of a voltage source

(a) is the highest when no load is applied
(b) does not influence the terminal voltage
(c) depends upon the internal resistance of the source
(d) decreases with increase load current

Solution: (c)

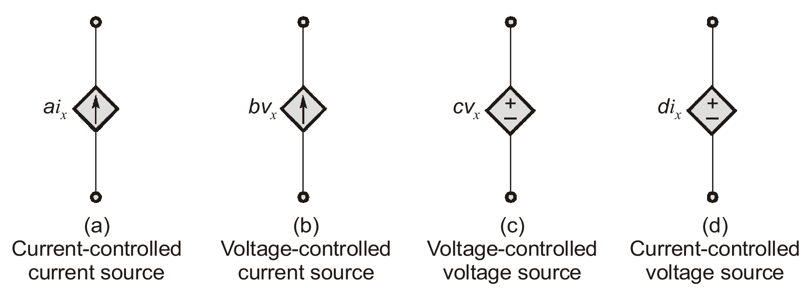
Internal voltage drop depends upon internal resistance,



Internal voltage drop, $\Delta V = E - V$ and $\Delta V = iR$, if load is present.

1.5.3 Dependent Sources

- The two types of sources that we have discussed up to now are called independent sources because the value of the source quantity is not affected in any way by activities in the remainder of the circuit.



(The four different types of dependent sources)

- This is in contrast with yet another kind of ideal source, the dependent, or controlled source, in which the source quantity is determined by a voltage or current existing at some other location in the system being analyzed.

NOTE

- Diamond shape is used for symbol to represent dependent sources.
- A dependent source may absorb or supply power.

1.6 Standard Input Signals

- Some of the standard signals used as excitation in electrical networks. These are:

1.6.1 Step Signal

- The step is a signal whose value changes from one level (usually zero) to another level A in zero time.

Student's Assignment

Q.1 The minimum requirements for causing flow of current are
(a) a voltage source, a resistor and a switch.
(b) a voltage source, a conductor, an ammeter and a switch.
(c) a voltage source and a conductor.
(d) a power source and a bulb.

Q.2 Two resisters R_1 and R_2 give combined resistance of 4.5 Ω when in series and 1 Ω when in parallel. The resistances are
(a) 1 Ω and 3.5 Ω (b) 4 Ω and 0.5 Ω
(c) 2 Ω and 2.5 Ω (d) 1.5 Ω and 3 Ω

Q.3 The V-I characteristic of a resistor is $I = 2V^2$. The resistor is
(a) linear, passive, bilateral
(b) non-linear, passive, bilateral
(c) non-linear, active, bilateral
(d) non-linear, active, unilateral

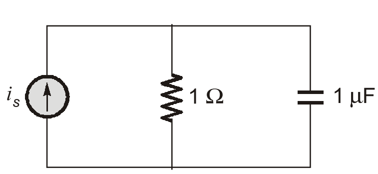
Q.4 Which of the following is not equivalent to Watts?
(a) Amperes × Volts (b) Joules/second
(c) Amperes/Volts (d) $(\text{Amperes})^2 \times$ Ohm

Q.5 A parallel plate capacitor is filled with two dielectrics of ε_1 and ε_2 lengthwise equally. The capacitance of the combination is

(a) $\dfrac{\varepsilon_0 A(\varepsilon_1 + \varepsilon_2)}{2d}$ (b) $\dfrac{2\varepsilon_0 \varepsilon_1 \varepsilon_2 A^2}{d^2}$

(c) $\dfrac{2\varepsilon_0 \varepsilon_1 \varepsilon_2 A}{d}$ (d) $\dfrac{A\varepsilon_1 \varepsilon_2}{d}$

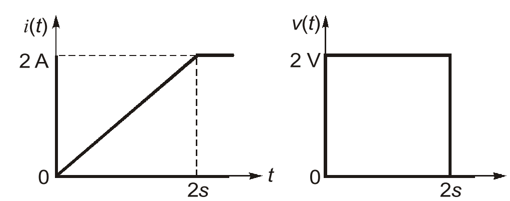
Q.6 In the circuit shown in the figure below, if $i_s = u(t)$ A, then what are the initial and steady-state voltages across the capacitor?



(a) 1 V and 1 V, respectively
(b) 1 V and 0, respectively
(c) 0 and 1 V, respectively
(d) 0 and 0, respectively

Q.7 A balanced delta connected load has an impedance of 9 ∠30° ohms per phase. What is the impedance per phase of its equivalent star?
(a) 27∠30° Ω (b) 27∠90° Ω
(c) 3∠30° Ω (d) 3∠20° Ω

Q.8 The voltage and current waveforms for an element are shown in the figure.



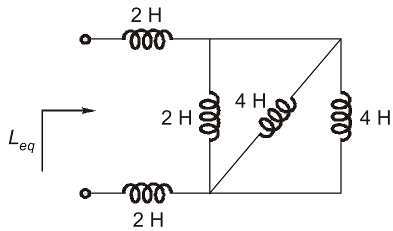
The circuit element and its value are
(a) Capacitor, 2 F (b) Inductor, 2 H
(c) Capacitor, 0.5 F (d) Inductor, 0.5 H

Q.9 Consider the following:
Energy storage capability of basic passive elements is due to the fact that
1. resistance dissipates energy
2. capacitance stores energy
3. inductance dissipates energy
Which of the above is/are correct?
(a) 1, 2 and 3 (b) 1 and 3
(c) 3 alone (d) 1 and 2

Q.10 If a unit step current is passed through a capacitor what will be the voltage across the capacitor?
(a) 0 (b) A step function
(c) A ramp function (d) An impulse function

Q.11 A coil of inductance 2 H and resistance 1 Ω is connected to a 10 V battery with negligible internal resistance. The amount of energy stored in the magnetic field is
(a) 8 J (b) 50 J
(c) 25 J (d) 100 J

Q.12 Find the equivalent inductance of the following circuit:



(a) 3 H (b) 5 H
(c) 4 H (d) 7 H

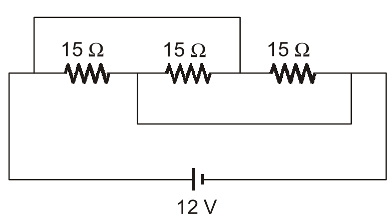
Q.13 The current in a coil changes from 5 A to 1 A in 0.4 second. The induced voltage is 40 V. The self-inductance in Henry is

(a) 1 (b) 2
(c) 4 (d) 10

Q.14 Two bulbs of 100 W/250 V and 150 W/250 V are connected in series across a supply of 250 V. The power consumed by the circuit is

(a) 30 W (b) 60 W
(c) 100 W (d) 250 W

Q.15 For the circuit shown below, the equivalent resistance will be

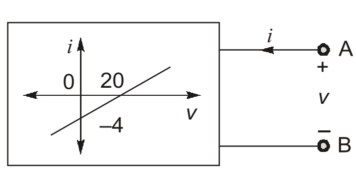


(a) 45 Ω (b) 15 Ω
(c) 5 Ω (d) 7.5 Ω

Q.16 The circuit whose properties are same in either direction is known as:

(a) bilateral circuit (b) irreversible circuit
(c) tank circuit (d) universal circuit

Q.17 The resistance seen from the terminals A and B of the device whose characteristic is shown in the figure below is



(a) –5 Ω (b) –1/5 Ω
(c) 1/5 Ω (d) 5 Ω

Q.18 The number of 2 μF, 300 V capacitors needed to obtain a capacitance value of 2 μF rated for 1200 V is

(a) 16 (b) 12
(c) 10 (d) 8

ANSWER KEY — STUDENT'S ASSIGNMENT

1. (c)	**2.** (d)	**3.** (b)	**4.** (c)	**5.** (a)
6. (c)	**7.** (c)	**8.** (b)	**9.** (d)	**10.** (c)
11. (d)	**12.** (b)	**13.** (c)	**14.** (b)	**15.** (c)
16. (a)	**17.** (d)	**18.** (a)		

HINTS & SOLUTIONS — STUDENT'S ASSIGNMENT

3. (b)

$$I = 2V^2$$

$$R = \frac{V}{I} = \text{constant}$$

Also, $$R = \frac{dV}{dI} = \frac{1}{4V}$$

As R depends on V
Its a non-linear resistor.
Resistor is a passive element.

5. (a)

Since the two dielectrics fill space equally, therefore area becomes $A/2$.

Now, $$C = \frac{\varepsilon A}{d} = \frac{\varepsilon_0 \varepsilon_r A}{d}$$

So, $$C_1 = \frac{\varepsilon_0 \varepsilon_1 A}{2d}$$

and $$C_2 = \frac{\varepsilon_0 \varepsilon_2 A}{2d}$$

Hence, $$C_{eq} = C_1 + C_2 = \frac{\varepsilon_0 A(\varepsilon_1 + \varepsilon_2)}{2d}$$

6. (c)

At steady state, capacitor acts as O.C. and at initial state it acts as S.C. to dc current.